covering, but similar environment as regards soil and moisture.

	Station—	
	No. 1.	No. 2.
	° F.	° F.
Average maximum temperature at surface in open	89.1	96.6
Excess at No. 2		7.5
Average minimum temperature at surface in open	48.8	46.1
Excess at No. 1	2.7	....

Station No. 1.—Peat soil with sanded surface; vegetation thin.
Station No. 2.—Peat soil with sanded surface; vegetation heavy.

The above data, of course, represent average values, including cloudy weather as well as clear, but it is during clear weather naturally, when critical temperatures are most likely, that the advantage of bare soil over dense growth is most apparent in the resulting temperature conditions. In several instances during the cranberry marsh research the maxima in dense vegetation under the most favorable conditions exceeded that over bare soil by from 10° to 15°, the minima the following morning in the rank growth being from 5° to 8° lower.

PREDICTING MINIMUM TEMPERATURES IN THE VICINITY OF WALLA WALLA, WASH.

By CHARLES C. GARRETT, Meteorologist.

[Weather Bureau, Walla Walla, Wash., August 14, 1922.]

Beginning with the spring frost season of 1915, a localized frost-warning service has been maintained at the Weather Bureau office at Walla Walla, Wash., for the benefit of orchardists and truck gardeners in various districts of southeastern Washington and northeastern Oregon. At one time the district included orchard sections as far away as the Umatilla irrigation project, near the junction of the Umatilla and Columbia Rivers in Oregon, and the White Bluffs project, on the west bank of the Columbia north of the mouth of the Snake River, but the area has been diminished considerably in the last two or three seasons.

As is the case in all of the commercial fruit-growing regions, the extent of orchard-heating operations for the purpose of combating frost is largely dependent upon local economic conditions, and interest in the matter increases and diminishes following seasons with greater or less frost damage.

The cost of installing orchard-heating equipment and the cost of fuel-oil and extra labor of filling and lighting the containers add materially to the running expenses of an orchard. If the prices received by the growers for their products are low, many do not consider that it pays to go to the extra expense of equipping their orchards with frost-fighting devices. Particularly is this true in a region similar to the Walla Walla Valley, which is usually quite free from severe frost damage. In the last two or three seasons heating has been confined mostly to prune and a few peach and cherry orchards. Practically no effort is now made to heat the large commercial apple orchards anywhere in the district. The question as to the effectiveness of orchard heating, when properly carried on, is not now often raised in this district, as it has been quite conclusively demonstrated by a number of prominent orchardists that the temperature within a heated orchard can be raised several degrees above that on the outside. The only question is that of the desirability of going to the extra trouble and expense.

Even though the number of orchardists in the Walla Walla district who are prepared to smudge or heat their orchards is relatively small, a considerable demand exists each season for accurate forecasts of minimum temperatures on critical nights for the fruit. A forecast merely of light, heavy, or killing frost, while of value, is not sufficient.

In addition to a careful study of the morning and evening weather charts, the methods of forecasting minimum temperatures are based primarily on readings of a maximum thermometer and readings of dry and wet bulb thermometers taken, preferably, in the early evening. The instruments should be exposed in a ground shelter under conditions approaching as closely as possible those existing in the orchards.

Studies of different methods have been made by a number of investigators, and explanations published in various numbers of the MONTHLY WEATHER REVIEW,[1] and in MONTHLY WEATHER REVIEW SUPPLEMENT No. 16.

(*Method A*) *Dewpoint-relative-humidity charts*.—This method is based on the well-known relationship between evening hygrometric data and ensuing morning minimum temperature. On a comparatively calm, clear night a knowledge of the value of the evening dewpoint enables one to approximate the minimum temperature of the following morning provided the relative humidity is taken into consideration along with the dewpoint. The depression of the minimum temperature below the evening dewpoint is greater when the moisture content of the air is low than in the case where there is a greater supply of moisture. If the relative humidity is comparatively low the dewpoint will be reached later in the night, if reached at all, than if the relative humidity is high. To best utilize the observations of dewpoint and relative humidity in the practical work of forecasting minimum temperatures it has been found convenient to chart the observations on cross-section paper. The relative humidity data are indicated at the bottom of the chart, while figures at the left indicate the differences between the dewpoint at the evening observation and the minimum temperature of the following morning. A dot is entered on the diagram to agree with the observed relative humidity and the variation of the minimum from the dewpoint temperature.

Dot charts have been prepared at the Walla Walla station, one for the first and one for the last half of the spring-frost season. Data for all the clear and mostly clear nights for several seasons were used—a period long enough to afford a fair test of the practical value of the method. On the Walla Walla charts the dots arranged themselves in the form of a parabolic curve. The curve of nearest fit through the dots was calculated by the "star point method." A full explanation of the process employed for calculating the curve is given by Prof. J. Warren Smith in MONTHLY WEATHER REVIEW SUPPLEMENT No. 16. Where many observations are available for making the dot charts the line or curve of nearest fit may be drawn with fairly good results free-hand instead of making use of a mathematical calculation.

By the use of the charts the forecaster, knowing the evening relative humidity and dewpoint at his station, can arrive at a close estimate of the probable minimum temperature at the "key station" on the following

[1] MO. WEATHER REV., October, 1914; August, 1917; May, 1918.

morning. The charts are of value only on comparatively clear nights, when nocturnal radiation is mostly uninterrupted. Clouds and wind, especially when they occur near the normal time of minimum temperature, serve to check the temperature drop, resulting in a higher minimum than would have been reached if the night had been clear throughout. However, errors in the forecast due to these causes are on the *safe* side; that is, the minimum that is reached is higher than the predicted minimum. Errors on the *unsafe* side (minimum lower than predicted) would result from the importation during the night of colder air from outlying regions. In the Walla Walla district, and other orchards west of the Rockies, fortunately, such a condition occurs very rarely in the spring. A close study of the evening weather map is the forecaster's recourse under such conditions. (See MONTHLY WEATHER REVIEW SUPPLEMENT No. 16.)

(*Method B.*) *Relation between maximum and minimum temperatures.*—A diagram showing the relation between the maximum temperature of the day and the minimum temperature of the following morning has also been prepared at Walla Walla, the data employed being those for the same nights used in preparing the hygrometric charts. On the maximum-minimum chart the dots fit quite closely along a straight line. The minimum temperature estimated from the diagram has fairly closely approximated the actual minimum recorded on nights of good radiation. An average of the minima indicated by the dewpoint-relative-humidity chart and the maximum-minimum chart gives very satisfactory results if clear weather prevails.

(*Method C.*) *Subtracting a constant from the evening wet-bulb temperature.*—Investigations carried on by the Swedish meteorologist Anders Ångström[2] resulted in his finding that the minimum temperature could be closely estimated by subtracting a constant from the evening wet-bulb temperature, best results being obtained when the wet-bulb thermometer was read at about sunset. Following out this suggestion, the present writer has calculated the average variation at Walla Walla for 121 nights in the six seasons 1917 to 1922, inclusive, and found it to be 10.5° for the first part of the season, March 15 to April 15, and 11° for the last part, April 16 to May 31. The greatest difference between wet-bulb and minimum was 16°, and the least 6°. By subtracting the constant of 11° for the 121 nights the minimum would have been predicted within 3°, or less than 86 per cent of the time. A comparison of the predicted minimums obtained by use of the hygrometric charts and those obtained by subtracting the constant from the evening wet-bulb temperature shows that the indicated minimums were nearly the same in every case. The Ångström method is certainly a simple and easily arrived at one of deciding on the probable minimum temperature from wet-bulb readings alone on nights of good radiation.

(*Method D.*) *Predicting the minimum temperature from the median temperature hour.*—An additional aid to the forecaster is what is termed the median temperature method. By the median temperature is meant the halfway temperature between the afternoon maximum and the ensuing morning minimum. On nights of good radiation, when meteorological factors other than the normal nocturnal fall are not involved, the median temperature falls at nearly the same time in the evening, except that the time becomes later as the season advances. It has been found at Walla Walla that the average time is about 7:40 p. m. for the last half of March, 7:55 p. m. for the first half of April, 8:05 p. m. for the last half of April, 8:15 p. m. for the first half of May, and 8:25 p. m. for the last half of May. By noting at the proper time the number of degrees fall from maximum temperature that has taken place, and subtracting that value from the current temperature, a figure that will agree fairly closely with the next morning's minimum will be obtained. The median time method, obviously, can be used only for late evening warnings. (See MONTHLY WEATHER REVIEW, October, 1914, p. 581.)

The working method at the Walla Walla station has been to average the minimum temperatures that have been estimated by the various methods, taking into consideration the observed local conditions and the general barometric and weather conditions as shown by the p. m. weather chart. Of course, blind reliance must not be placed on any formula or set of rules for predicting minimum temperatures, but the experience of those who have studied the relationship of evening hygrometric data to morning minimum temperatures, as well as the relation of maximum to minimum, and applied the result of their studies to the practical work of forecasting, taking into account other factors in their proper relation, has resulted in renewed confidence in their ability to forecast closely the minimum temperatures on critical nights for fruit and vegetable growers.

In a district where temperature conditions may vary considerably in the different local areas the aid of cooperative observers is necessary for best results. Where it is not easy to obtain uniformly reliable readings of the wet and dry bulb thermometers, due to inexperience or lack of available time on the part of the cooperative observer, a knowledge of the thermal relationship between the outlying districts and a central "key" station can be had through comparative readings of self-recording minimum thermometers, or records of thermographs, covering a period of several seasons.

In the accompanying table appear the results of using the various methods described in this paper, for a number of typical radiation nights during the four seasons 1919 to 1922, inclusive. The dates selected were all those after March 15, when heavy to killing frost occurred at Walla Walla. The table shows, in addition to the results obtained by the application of each method, the estimated minimum obtained by averaging those estimated by all the methods.

[2] Anders Ångström: Studies of the Frost Problem, 1. *Geografiska Annaler*, 1920, H. 1.

TABLE 1.—*Minimum temperature estimates for Walla Walla, Wash., on nights during the spring seasons 1919 to 1922, inclusive, using hygrometric, maximum-minimum, and median temperature methods. (Dates given in the table include all nights after March 15, with heavy or killing frost.)*

Date.	Hygrometric chart method.	Maximum-minimum method.	Constant subtracted from wet-bulb temperature.	Median temperature method.	Average of all methods.	Recorded minimum.	Difference.
1919.							
Mar. 20	34	31	31	26	30	29	+1
21	32	34	32	29	32	32	0
22	29	33	33	26	30	30	0
24	33	35	32	26	32	30	+2
25	25	28	27	23	26	29	−3
26	29	32	31	30	30	31	−1
Apr. 12	28	30	30	26	28	30	−2
15	31	33	30	28	30	29	+1
May. 4	30	31	31	34	32	31	+1
1920.							
Mar. 17	21	25	25	23	24	25	−1
1921.							
Mar. 27	28	30	28	24	28	30	−2
30	30	33	31	27	30	31	−1
31	31	35	32	27	31	31	0
Apr. 4	22	....	26	34	27	29	−2
7	27	31	28	23	27	30	−3
8	30	32	29	29	30	30	0
9	31	37	34	26	33	31	+2
1922.							
Mar. 28	25	25	27	....	26	28	−2
Apr. 12	28	28	26	24	26	29	−3
May 9	28	33	28	26	29	29	0

THE TEMPERATURE AT PORTO VELHO, AMAZONAS, BRAZIL.

By ALFRED J. HENRY.

Through the courtesy of Dr. Frederick L. Hoffman, statistician, Prudential Insurance Co., the Weather Bureau has been supplied with almost 14 years of climatological observations made by the Engineering Department of the Madeira-Mamore Railway at its eastern terminal, Porto Velho, on Madeira River just above the point where navigation on that river is interrupted by rapids and falls.

The monthly totals of rainfall will appear in an early number of this REVIEW.

The temperature observations were made at the hours 6:30 and 11:00 a. m. and 3:00 and 6:30 p. m. except that the last-named hour was changed to 5:30 beginning with June, 1917. No one of these hours alone, or any combination of them which might be made, would yield results that would closely approximate the mean temperature of the 24 hours, hence the means for each separate hour have been computed and are presented in Table 1. These data give a close approximation to the daily range in temperature for each month of the year. It may be seen by simple inspection that the mean temperature rises about 10° daily from 6:30 a. m. to 3:00 p. m. during the wet season, which extends from November to May, and as much as 15°, on the average, in the winter or dry season. Since the occurrence or nonoccurrence of showers in the afternoon would have an important influence on the afternoon maximum, it is inferred that relatively dry months in the wet season would be favorable to high temperature.

The highest temperature recorded at any of the observing hours was 104° F. in October, 1914. Temperatures of 100° F. were also recorded in August and October, 1916, and in September, 1917. September is the month of greatest maxima and February the least.

The lowest temperature recorded during the period of observations was 56° F. in June, 1916, at 6:30 a. m. I have compiled from the daily observations the observed extremes for each month and present them in Table 2. The means given at the bottom of this table may be considered as approximate means of the monthly extremes from which may be obtained the average monthly range of temperature. An inspection of these mean results shows that the range is greatest in the winter months of June-August and least in the summer months of January-February.

It is interesting to note that Porto Velho temperatures were at a maximum in 1914–15, and at a minimum in 1916–17, as noted for Arequipa.[1]

TABLE 1.—*Monthly mean temperature at Porto Velho, Brazil, for the hours named, January, 1908, to November, 1921.*

[Approximate latitude 8° 44′ S., longitude 64° 00W. Elevation, —.]

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
6:30 a. m.	76.1	76.2	76.2	76.4	75.5	73.4	72.2	73.9	76.0	76.5	76.3	76.0	75.4
11:00 a. m.	82.1	82.1	82.8	83.2	83.6	83.1	83.9	85.4	86.3	85.2	84.2	82.5	83.7
3:00 p. m.	85.1	85.1	85.5	85.2	86.1	86.5	88.2	90.4	90.6	88.5	87.0	85.3	87.0
6:30 p. m.	82.6	82.5	82.6	83.0	83.1	83.9	85.7	86.3	86.6	85.1	83.8	82.9	84.0

TABLE 2.—*Approximate monthly extremes of temperatures for Porto Velho, Amazonas, Brazil.*

[Maxima taken mostly from observations at 3 p. m. and minima taken from the 6:30 a. m. observations.]

Year.		Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1908	max.	93	92	95	95	91	95	91	94	96	93	92	92	96
	min.	73	72	72	73	66	65	63	63	67	72	72	70	63
1909	max.	93	89	90	89	89	90	91	96	97	96	93	91	97
	min.	72	72	72	72	57	63	57	58	63	72	70	70	57
1910	max.	93	90	87	90	90	90	92	96	98	95	98	91	98
	min.	71	73	74	73	69	67	68	62	74	72	77	73	62
1911	Max.	92	94	91	91	92	89	94	95	97	94	94	92	97
	min.	74	74	70	71	70	58	63	66	70	70	75	75	58
1912	max.	94	94	94	91	92	90	93	94	94	94	91	93	94
	min.	75	76	74	74	71	75	58	68	68	76	75	73	58
1913	max.	92	91	92	91	90	90	94	99	97	94	95	97	99
	min.	74	75	75	74	72	70	68	66	72	74	75	68	66
1914	max.	90	90	92	93	92	94	93	96	96	104	98	94	104
	min.	74	76	74	72	68	70	71	70	73	74	72	72	68
1915	max.	96	94	96	96	98	92	95	98	95	95	93	92	98
	min.	74	72	76	74	74	62	58	70	70	74	72	71	58
1916	max.	90	90	92	92	93	92	94	100	98	100	94	90	100
	min.	72	72	72	73	72	56	66	68	68	70	64	72	56
1917	max.	92	90	91	92	90	94	96	98	100	94	92	90	100
	min.	72	70	72	72	60	65	64	62	62	70	72	72	60
1918	max.	90	87	88	89	92	92	93	93	95	95	97	94	97
	min.	71	72	72	72	71	59	62	67	70	73	70	71	59
1919	max.	94	91	93	93	96	96	96	97	97	96	96	94	97
	min.	70	75	74	72	76	66	72	60	68	72	74	75	60
1920	max.	94	92	93	92	93	95	96	96	96	94	98	92	98
	min.	75	74	76	71	74	61	66	63	65	72	73	74	63
1921	max.	96	96	92	93	94	95	95	98	98	96	......	......	98
	min.	76	74	74	72	73	60	60	64	64	70	......	......	60
Mean max.		92.8	91.4	91.9	91.9	93.1	92.5	93.8	96.3	96.7	95.7	94.7	92.4	98.0
Mean min.		73.1	73.3	73.3	72.7	69.5	64.3	64.0	64.8	68.1	72.2	72.4	72.0	60.6

[1] Cf. this REVIEW 508.